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# AN EVALUATION OF RISE TIME CHARACTERIZATION AND PREDICTION METHODS

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## INTRODUCTION

One common method of extrapolating sonic boom waveforms from aircraft to ground is to calculate the nonlinear distortion, and then add a rise time to each shock by a simple empirical rule. One common rule is the "3 over P" rule which calculates the rise time in milliseconds as three divided by the shock amplitude in psf[1].

This rule was compared with the results of ZEPHYRUS, a comprehensive algorithm which calculates sonic boom propagation and extrapolation with the combined effects of nonlinearity, attenuation, dispersion, geometric spreading, and refraction in a stratified atmosphere[2]. It is shown here that the simple empirical rule considerably overestimates the rise time estimate. In addition, the empirical rule does not account for variations in the rise time due to humidity variation or propagation history.

It is also demonstrated that the rise time is only an approximate indicator of perceived loudness. Three waveforms with identical characteristics (shock placement, amplitude, and rise time), but with different shock shapes are shown to give different calculated loudness.

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## RISE TIME VS. PRESSURE AMPLITUDE

A number of waveform propagation calculations were performed, using the ZEPHYRUS algorithm, for the case of an aircraft moving at Mach 1.5 at an altitude of 55,000 feet (16,764 m). For simplicity, the initial sonic boom waveform was modeled as an N-wave 200 msec in duration. The calculations were performed for a number of initial wave amplitudes and ground-level humidities. In each case, the initial waveform was extrapolated to the ground, and the ground-level amplitude and rise time of the initial shock was calculated (here, the rise time is calculated as 10% to 90% of peak amplitude). These results are plotted in Fig. 1. This is compared with the "3 over P" prediction.

Three features are immediately evident. First, the "3 over P" method has no humidity dependence, which is clearly evident in the ZEPHYRUS results. Second, the "3 over P" method considerably overestimates the ZEPHYRUS calculation for every case, with the best agreement for very dry air. Finally, the "3 over P" method comes closer to agreement with the ZEPHYRUS results for high amplitude waves, with increasing overestimation as the amplitude decreases.

The consistent overestimation is probably due, in part, to the fact that the "3 over P" curve is based upon the rise time corresponding to a steady-state step shock, or a well-developed shock in which the mechanisms affecting rise time have reached a state of equilibrium for the environment at ground level. However, it has been demonstrated by Raspet, Bass, Yao, and Wu[3], as well as by this author[4], that the typical healing distance of the shocks at ground level is on the order of hundreds of meters to kilometers, a longer distance than that for which the ground-level conditions have been in effect along the propagation history, and thus the shocks at ground level are not in steady-state. If the propagation history is accounted for, as in the ZEPHYRUS result, shorter rise times are predicted.

The angle of incidence of the sonic boom with the ground depends upon the aircraft Mach number. Longer rise times, closer to steady-state, would be expected for Mach numbers close to one, in which the incident wave is closer to a grazing angle with the ground, and thus the wave is at near ground conditions for a longer period in its propagation history. Of course, significant refraction effects would be expected in this regime.

## RISE TIME AND SHOCK SHAPE

It has also been demonstrated previously by this author that, for the same ground-level pressure amplitude, the rise time varies considerably as a function of the slope of the waveform behind the lead shock[4]. Thus, the shape of the waveform near the shock is also important in determining rise time.

The shape of the shock itself is also of intrinsic importance. Although the shock rise time is useful as a rough indicator of the expected loudness, too much reliance on the rise time can be misleading. The shape of the shock has a strong effect on the high-frequency content of the sonic boom and thus on the loudness. In Fig. 2, three waveforms are shown with identical shock characteristics (shock placement, rise time, and amplitude), but with different shock shapes: (1) linear step shock, (2) shock interpolated with a hyperbolic tangent, and (3) the ZEPHYRUS prediction. The loudness of each waveform was computed using the SIG7CZ code (written by Brenda Sullivan at NASA Langley), and the results are displayed in Table 1.

Table 1. Loudness Results

|  | dB (PL) | dBC | dBA |
|---|---|---|---|
| Step shock | 93.32 | 98.27 | 78.91 |
| Tanh | 92.29 | 98.29 | 78.70 |
| ZEPHYRUS | 95.59 | 98.29 | 82.27 |

For the PL and A weightings, the ZEPHYRUS prediction is several dB louder than the other predictions. The reason can be seen in Figs. 3 and 4, which display the leading and tailing shocks. In the ZEPHYRUS prediction, the dispersion due to the molecular relaxation effects is shown to

produce a highly asymmetric shock with a very steep initial phase. In turn, the high frequency content corresponding to this steep initial phase produces the increase in loudness.

## CONCLUSIONS

It has been shown here that simple methods of sonic boom extrapolation may be too crude to give accurate predictions, as they ignore the effects of humidity, propagation history, and waveform shape. In addition, the commonly used "3 over P" rule considerably overestimates the rise time.

The rise time is a useful indicator of loudness, but may be relied upon too much. It has been shown here that the shock shape can affect the loudness of the overall waveform. Simple shock interpolations may produce a loudness estimate that is too low by several dB. In the case of the "3 over P" rule, this underestimation of loudness would be further exacerbated by the rise time overestimation.

## REFERENCES

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4.  Robinson, Leick: A Numerical Model for the Propagation of Sonic Booms through an Inhomogeneous, Windy Atmosphere. Presented at the 123rd Meeting of the Acoustical Society of America, Salt Lake City, Utah, May 11-15 1992.
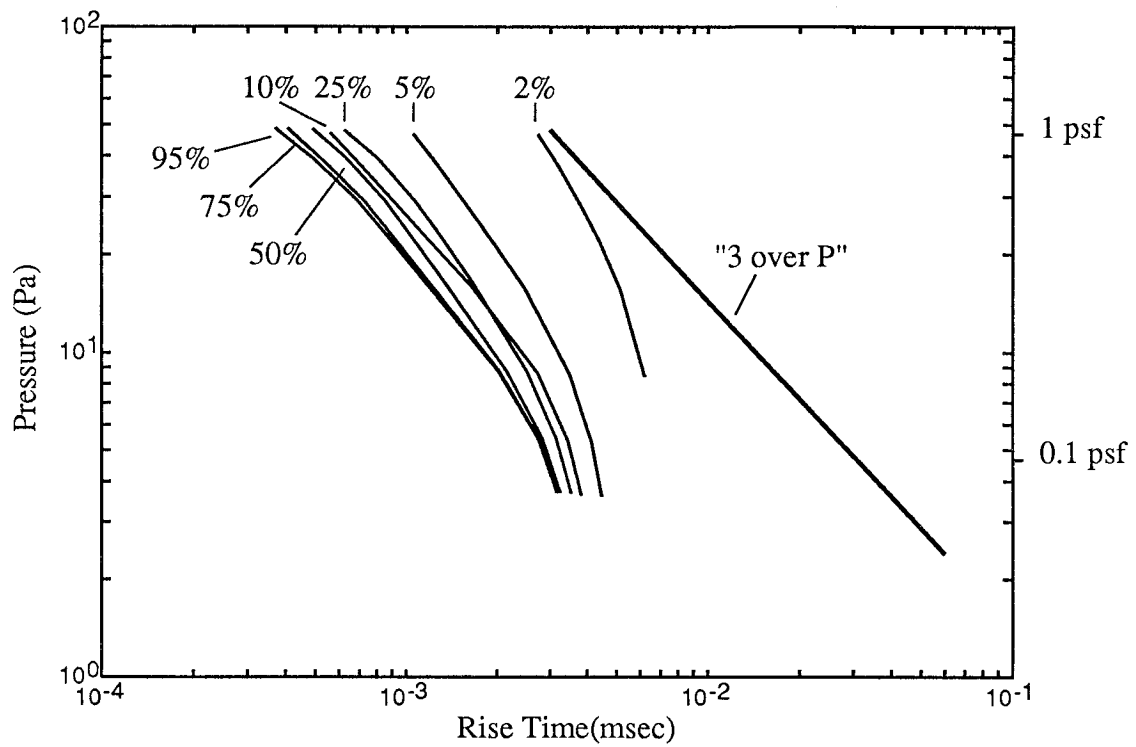
Figure 1. Rise time vs. shock amplitude for 2%, 5%, 10%, 25%, 75%, and 95% relative humidity at ground level and the "3 over P" curve
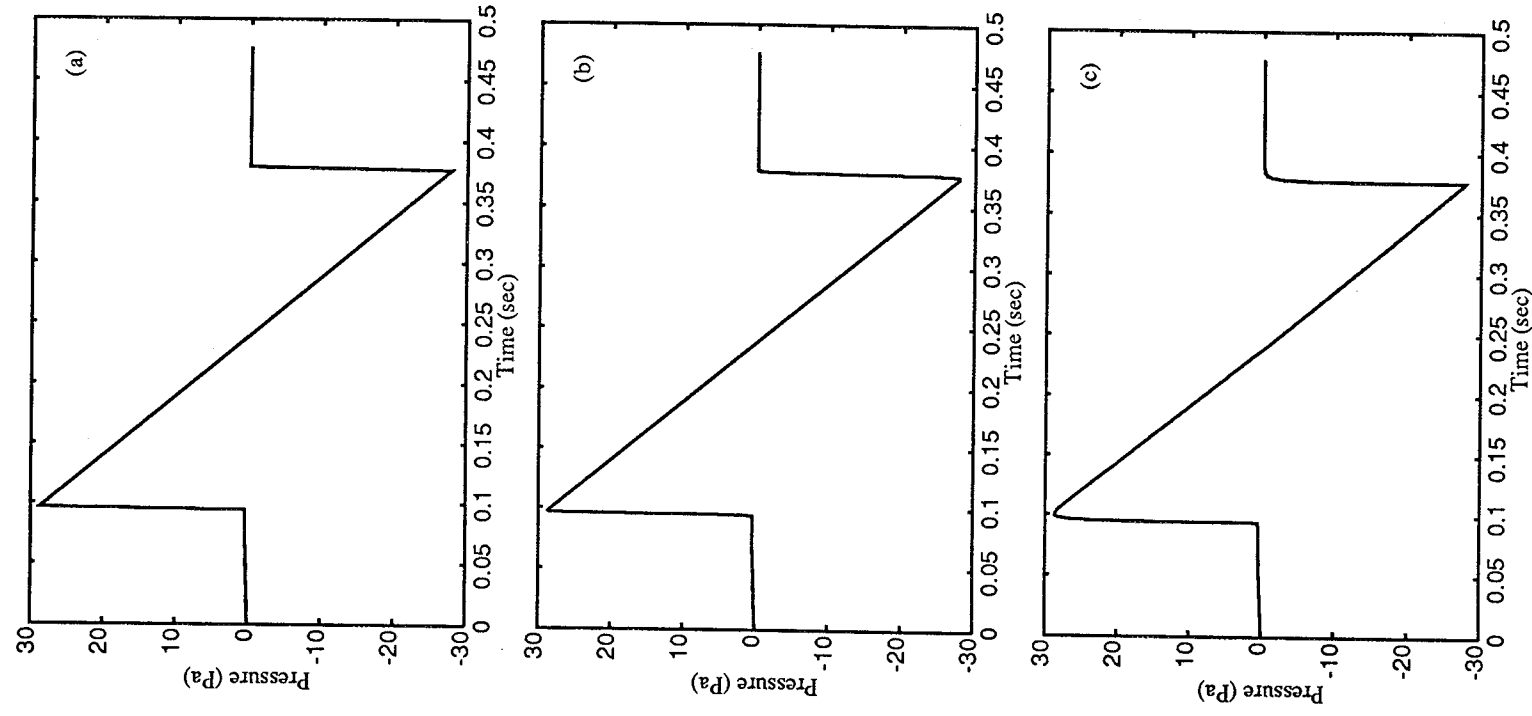
Figure 2.  Calculated waveforms:  (a) linear step shock, (b) hyperbolic tangent, and (c) the ZEPHYRUS prediction
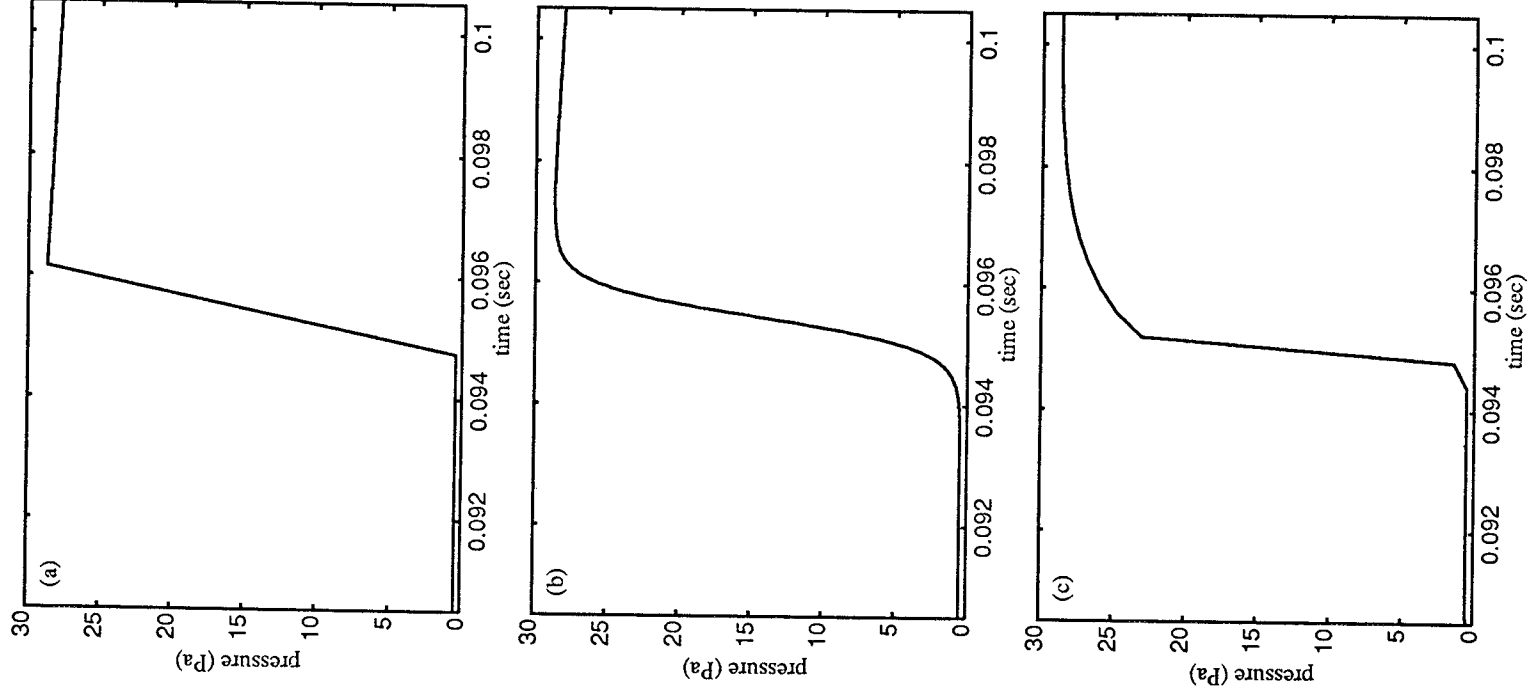
Figure 3. Leading shock: (a) linear step shock, (b) hyperbolic tangent, and (c) the ZEPHYRUS prediction
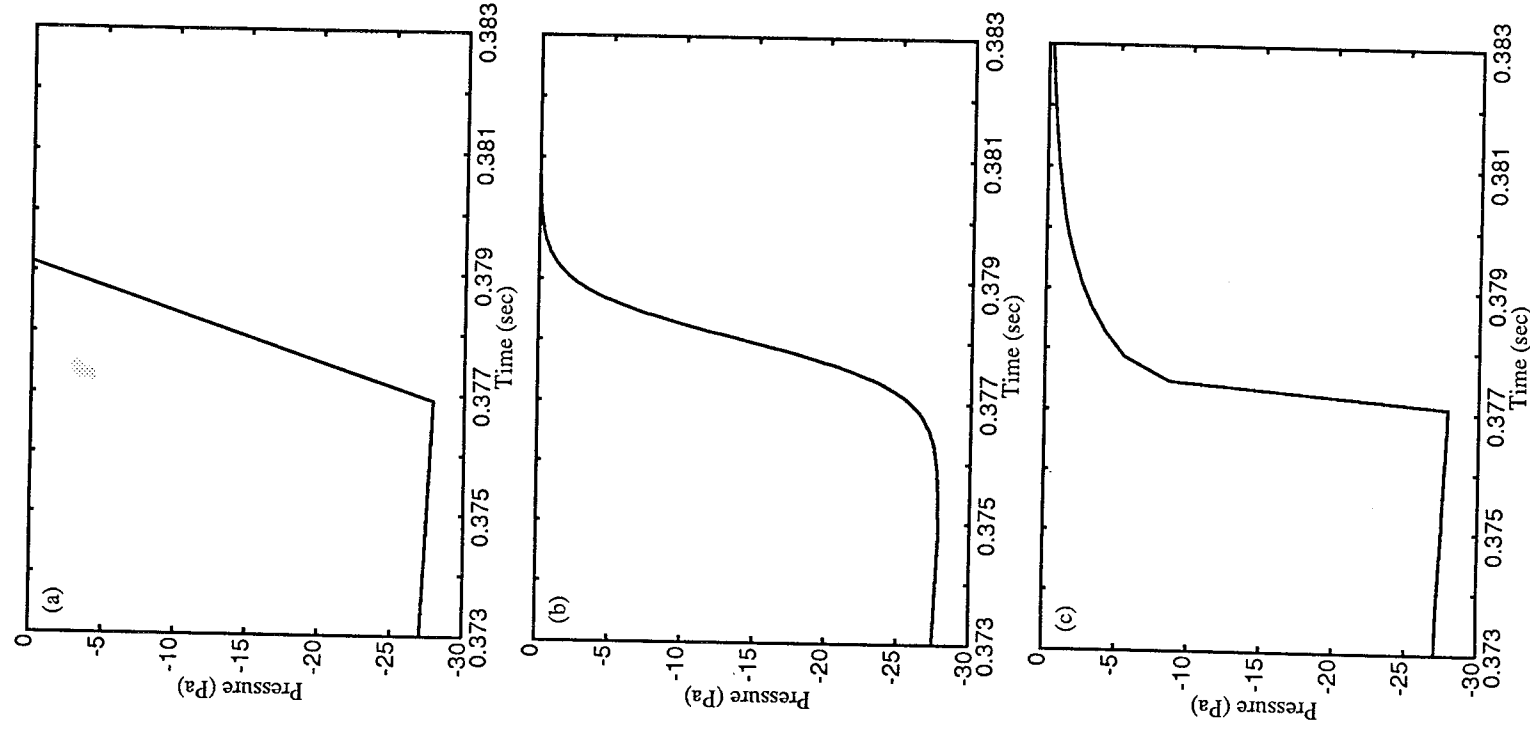
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Figure 4. Trailing shock: (a) linear step shock, (b) hyperbolic tangent, and (c) the ZEPHYRUS prediction